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Optimal deterrence under misperception of the probability of apprehension and the magnitude of sanctions

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Abstract

A standard result in the literature is that agents may be incentivized to obey socially optimal regulations by modulating either the probability of apprehension or the sanction once apprehended. Several studies investigate the conditions under which agents may be relatively more sensitive to increases in the probability as opposed to increases in the sanction. These studies assume agents have perfect information regarding one or both of the probability and the sanction. Yet, other studies show that agents routinely misperceive both the objective probabilities and the sanctions they face. This paper weaves several studies into a general model that enables theoretical exploration of unidimensional and multidimensional misperception upon deterrence policy. In turn, the theoretical model supports policy applications in a wide range of legal contexts beyond criminal, property, and torts, such as energy, health, and intellectual property, where agent compliance may be undermined by misperceptions.

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1. Introduction

A standard result in the literature is that agents may be incentivized to obey socially optimal laws/regulations/standards (LRSs) by modulating either the probability of apprehension or the sanction once apprehended. Several theoretical and empirical studies investigate the conditions under which agents may be relatively more sensitive to increases in the probability of apprehension as opposed to increases in the sanction once apprehended. These studies originated with Becker's (1968) economic analysis of crime and punishment and now include Polinsky and Shavell (1979), Lazear (2006), Loughran *et al.* (2012), Friesen (2012), Qin and Wang (2013), Mungan (2017), Bar-Gill (2017), Feess *et al.* (2018), and Salmon and Shniderman (2019).

Becker (1968) shows that a rational risk-neutral potential violator of a law should compare the expected sanction versus the expected benefit, where expected sanction is the probability of apprehension multiplied by the severity of sanction, and to be indifferent to changes in these two components that leave the expected sanction unchanged. Polinsky and Shavell (1979) have agents who face a known probability of apprehension and a known sanction if caught, where society's cost for raising the probability of apprehension increases at an increasing rate. Kaplow (1990) considers the case in which some agents accurately perceive that their actions are harmful and subject to a known sanction while other agents do not accurately perceive the likelihood that their actions are harmful and subject to sanction. Bebchuk and Kaplow (1992) find that when individuals misperceive the probability of apprehension but accurately perceive the sanction, it may not be optimal to set the sanction at the highest possible level. Setting the sanction at the highest possible level comes from Becker (1968), who shows that since increasing the probability of apprehension is socially costly (with the assumption that imposing sanctions is not costly) social policy should set the probability of apprehension as low as possible and then set the sanction as high as possible so that the low probability times the high sanction gives the socially optimal expected sanction. Posner (2004) analyzes the efficacy/efficiency of alternative tort rules (negligence versus strict liability) when people misperceive probabilities of apprehension. Lazear (2006) considers the problem of whether to narrowly target enforcement of standards like vehicle speed and income tax reporting or to broadly distribute enforcement resources to motivate a socially optimal probability of apprehension. Loughran *et al.* (2012) find that youthful offenders in their study show wide ranges of perceptions of the sanctions they face, and that this variation in perception is based upon differences in prior information individuals hold.

Friesen (2012, 400) notes that the consensus in the empirical literature is that increasing the probability of apprehension has a stronger impact on crime rates than increasing the sanction. She finds in experiments that increasing the severity of sanction is more effective for deterrence than increasing the probability of apprehension, in contrast to the empirical literature. Qin and Wang (2013) carry out an experiment in which participants face a uniform expected sanction for not contributing to a public good and find that greatest deterrence occurred with a 'medium' probability and 'medium' sanction, as opposed to high probability and low sanction or the low probability and high sanction (where all three combinations yielded the same expected sanction). Hence they reject the null hypothesis that different configurations of the same expected sanction would have no effect on contributions to a public good. Mungan (2017) notes that criminologists believe that increasing the probability of apprehension is more impactful than increasing the sanction, whereas experimental economics and relatively standard law and economics theoretical models predict the opposite. He argues that a way to reconcile these views is to introduce repeat

offenders facing escalating punishment. His theoretical model features a known probability of apprehension and a known sanction that is escalating by a known factor π for repeat offenders.

Bar-Gill (2017, 276) investigates how consumer misperception of law translates into consumer misperception of product quality and how such misperception affects prices, quantities, and social welfare. Feess *et al.* (2018, 61) have agents who assume there is a known probability of apprehension for violating the law and a known sanction if apprehended; they show that if judges are concerned about making Type I errors (convicting innocent people) and hence are concerned that large sanctions may be imposed on innocent people, the sanction will be inefficiently constrained unless the probability of apprehension can be raised to a sufficiently high level. Most recently, Salmon and Shniderman (2019) conduct experiments that explore how agent ambiguity over the probability of apprehension affect their decision-making when facing a known sanction. They find that when the probability of apprehension is ambiguous and then shifts, there is no clear behavioral response. They conclude that in the real world, simply announcing ambiguous changes to enforcement in hopes that agents will have pessimistic priors cannot be expected to have the desired deterrent effect. Instead, in general, public policy agents should announce quantified probabilities or changes in probabilities of apprehension.

To summarize, while the existing literature considers how agent decision-making changes according to the probability of apprehension or according to the magnitude of the sanction if apprehended, the literature does not yet appear to feature a general model within which to organize these forces and does not consider the impact of compound misperception—that is, misperception of both the probability and the sanction. The present analysis works toward filling this gap in the literature, showing theoretically how compound misperception creates both challenges and opportunities for Pareto-improving design of LRSs. The theoretical insights find application in a wide range of scenarios beyond property crimes and torts where most of the above literature resides. Indeed, there are many scenarios in which agent misperceptions of the likelihood of adverse outcomes and/or of the consequences from the adverse outcomes are salient. For instance, in the energy policy context, Shaffer (2020) finds that a surprising proportion of electricity consumers routinely misunderstand nonlinear pricing schedules, mistaking that the marginal price is the price of all units consumed rather than just the last unit consumed. In the language of the model presented herein, the 'probability of apprehension" maps to the "probability the agent incorrectly interprets the price schedule" and the "sanction if apprehended" maps to the financial penalty the consumer sustains under misperception. Shaffer cautions that economically efficient energy policies may therefore fail to reach their goals if consumers misperceive how first-best energy pricing structures actually work.

In the health policy context, Allcott *et al.* (2019) review the efficiency-restoring properties of sugar-sweetened beverage taxes when consumers misperceive nutrition information and the likelihood of adverse health impacts from their consumption. In the intellectual property context, Lemley and Shapiro (2005) describe the significant uncertainties involved in patent issuance and litigation in the US. They go so far as to liken patents to lottery tickets, given their finding that most issued patents have little to no commercial value; that relatively few patents are litigated; but that the patents that are litigated are more likely than not to be found invalid (with potentially large consequences). We might expect these substantial uncertainties to manifest themselves in quite a variance of misperceptions amongst patent holders and potential infringers regarding both the likelihood that infringement has occurred and the sanction that applies when

infringement does occur. Indeed, Guerrini *et al.* (2016) find in their survey of leaders in the gene-sequencing industry that there exist substantial misperceptions regarding applicable patent law and its enforcement. For instance, they find that interviewees consistently expressed the belief that some infringement activities were excusable because people's lives depend on scientists having access to patented technology or if the infringement occurred as an unintended byproduct of legitimate activities; yet, direct patent infringement is a strict liability tort and therefore the infringer's reasons and intentions are not relevant. In a different intellectual property context, Grzelka and Wagner (2019, 329-331) describe how taking uncertainty and resulting misperceptions at the intersection of intellectual property law and space law into fuller account can help manage the growing problem of satellite debris in low-Earth orbit.

In each of these contexts, LRSs are typically formulated with an eye toward the 'first-best' (in economic theory terms)—which is to say, the laws are designed to motivate economically efficient outcomes in a world in which affected parties have clear understandings of the likelihoods of adverse outcomes and the penalties when such outcomes arise. The focus of this paper is to take these possibly layered misperceptions into greater account, thereby improving the robustness of the models we rely upon for formulating effective, least-cost enforcement policies. The model is set forth in Section 2, where several prior studies are combined to clarify the components of optimal enforcement when there are no misperceptions and then when there are unidimensional and compound misperceptions. Conclusions and directions for future research are described in Section 3.

2. The Model

Consider the socially optimal deterrence of a risk-neutral agent who may choose to violate an LRS. The agent faces an objective probability p of being apprehended as well as an objective magnitude of sanction s should they be apprehended. Let $g(p, \theta_p)$ be a continuous and differentiable function that represents the *subjective* probability of being apprehended, where θ_p is a degree of potential misperception of the probability and $\frac{\partial g}{\partial p}, \frac{\partial g}{\partial \theta_p} > 0$. Similarly, let $h(s, \theta_s)$ be a continuous and differentiable function that represents the *subjective* sanction for apprehension and conviction, where θ_s is a degree of potential misperception of the sanction and $\frac{\partial h}{\partial s}, \frac{\partial h}{\partial \theta_s} > 0$. The *subjective* expected sanction can then be expressed in general form as:

$$\bar{S} = g(p, \theta_p)h(s, \theta_s) \tag{1}$$

To obtain concrete solutions, we need a specification for $g(p, \theta_p)h(s, \theta_s)$. One possibility is to let $g = (p + \theta_p)$ and $h = (s + \theta_s)$.[1] The formulation for the *subjective* expected sanction becomes:

$$\bar{S} = (p + \theta_p)(s + \theta_s), \tag{2}$$

whereupon $d\bar{S} = (s + \theta_s)dp + (p + \theta_p)ds = 0$ and, as in Bebchuk and Kaplow (1992, 368), the marginal rate of substitution potentially-offending parties perceive between the probability of

[1] Several specifications are possible; for example, Johansson-Stenman (2008, 236) has subjective risk *s* modeled as a function of objective risk, *r*, so that *s* = *s*(*r*).

apprehension and the sanction if apprehended is given by the slope at every point on every level curve of expected sanction:

$$\frac{ds}{dp} = -\frac{s+\theta_s}{p+\theta_p}. \quad (3)$$

As Becker (1968) describes, enforcement costs are not typically zero in either dimension and those costs need to be taken into account in order to determine optimal enforcement strategies. For tractability, assume linear marginal costs per lever of regulatory control. The regulator's budget constraint is:

$$B = c_p p + c_{\theta_p}\theta_p + c_s s + c_{\theta_s}\theta_s, \quad (4)$$

The social cost minimization is then:

$$\text{Min } \mathcal{L} = c_p p + c_{\theta_p}\theta_p + c_s s + c_{\theta_s}\theta_s + \lambda\left[\bar{S} - \left(p+\theta_p\right)(s+\theta_s)\right] \quad (5)$$

The first-order conditions lead the regulator to choose each of the four levers available such that their marginal costs just equal their marginal impact upon generating the expected sanction, and such that they generate the socially optimal expected sanction, $\bar{S}$. A few additional observations are in order before proceeding. First, note that in this specification, modulating either the objective or subjective values of either the probability or sanction have the same marginal effects. Second, this implies that if the marginal costs of modulating the objective or subjective values are constant but different, then only the cheaper modulation will be undertaken. Third, we see that it can be socially efficient for there to be a degree of misperception of the probability of apprehension or the sanction if apprehended or both. That is, the model shows that achieving social optimality requires regulators to take subjective citizen perceptions into account; these are necessary conditions for optimal deterrence. However, it need not be the case that optimal policy fully corrects all citizen misperceptions.

To set terms, suppose the expected public harm from a violation of an LRS is \$2000 and that there is no misperception of *p* or *s*. Suppose that $c_p = \$4000$ and $c_s = \$0.08$. To clarify the units involved, the constant, per-unit cost of $c_p = \$4000$ has the interpretation that the probability of apprehension could be set to 1 at a cost of \$4000, such that starting from any given probability below 1, the probability of apprehension could be raised by 0.1 at an incremental enforcement cost of \$400 or raised by 0.01 at an incremental cost of \$40. This is a simplification of probability of apprehension marginal enforcement cost; however, it permits concrete solutions that enable some initial intuition. Likewise, the constant, per-unit cost of $c_s = \$0.08$ means that the regulator incurs a cost of \$0.08 per \$1 of sanction it seeks to collect. This cost may include issuing a summons; holding court; and processing the violator's paperwork. It is easily verified that social optimality obtains with *p* = 0.2 and *s* = \$10,000—where the marginal rate of substitution between *s* and *p* (equal to -50,000) equals the slope of the enforcement isocost function (which is -4000/0.08 = -50,000). The resulting enforcement cost is \$1600.

Four cases of misperception in just one dimension and four cases of compound misperception are possible, as follows:

1. *p* is overestimated but *s* is perceived correctly. Cost < Baseline
2. *p* is perceived correctly but *s* is overestimated. Cost < Baseline
3. *p* is overestimated and *s* is overestimated. Cost < Baseline

4. p is underestimated but s is perceived correctly. Cost > Baseline
5. p is perceived correctly but s is underestimated. Cost > Baseline
6. p is underestimated and s is underestimated. Cost > Baseline
7. p is overestimated and s is underestimated. Cost vs. Baseline indeterminate
8. p is underestimated and s is overestimated. Cost vs. Baseline indeterminate.

First, consider the case in which potential violators overestimate the probability of apprehension p but accurately estimate the sanction s. Then $\theta_p > 0$ (the subjective probability $p + \theta_p$ is greater than the objective probability p) and $\theta_s = 0$. We see that Eq. (3) becomes:

$$\frac{ds}{dp} = -\frac{s}{p+\theta_p}, \tag{6}$$

and the MRS decreases relative to the baseline when $\theta_p = 0$. Our first instinct is that we would slide in the southeast direction along the $\bar{S}_0 = \$2000$ isoquant from bundle A to bundle B in Figure 1 below. However, doing so implies that the imposed sanction should be brought down to \$6,666.67 (since this is the sanction s that gives the socially optimal expected sanction of \$2000 when p = 0. 3). But if the potential violator only misperceives the probability of apprehension p and not the sanction s, the sanction is maintained at \$10,000 and the p need only be enforced to a level of 0.1 (point D on Figure 1). The regulator's budget constraint shifts parallel toward the origin; kinks at point D; and continues horizontally back to point A, since the potential violator's overestimation of p complements the regulator's costly effort to enforce 0.1 units of p with an additional 0.1 units of p. This enables the regulator to enforce the socially optimal expected sanction $\bar{S}_0$ at a *lower* expense of resources than if potential violators do not overestimate the probability of apprehension. The potential violator's overestimation of p effectively does some of the regulation for the regulator. Recall that the baseline enforcement cost (in which $\theta_p = 0$) is \$1600, where the constant per-unit costs of enforcement were $c_p = \$4000$ and $c_s = \$0.08$, respectively. When the regulator enforces to a level of p = 0.1 and forecasts that $\theta_p = 0.1$, the regulatory cost of achieving the socially optimal expected sanction of \$2000 falls to \$1200. The potential violator's overestimation of p saves the regulator \$400 of enforcement cost because the potential violator is providing 0.1 units of misperceived p for free.

In Case 2, potential violators believe the sanction they face is $(s + \theta_s)$ instead of s and they correctly perceive the probability of apprehension (so that $\theta_p = 0$). We see that the MRS increases and is now greater at Point F in Figure 1 than at Point A. However, since the expected sanction at F is \$3000—greater than the socially optimal sanction of \$2000—this implies that regulators would be able to enforce the socially optimal expected sanction $\bar{S}_0$ at a lower expense of resources than if potential violators do not overestimate the sanction. If the potential violator only misperceives the sanction s and not the probability of apprehension p, the probability is maintained at 0.2 and the sanction s need only be enforced to a level of \$5000 (point E on Figure 1). The regulator's budget constraint shifts parallel toward the origin along the x-axis; kinks at point E; and continues vertically back to point A. Since the potential violator's overestimation of s by \$5000 complements the regulator's costly effort to enforce \$5000 of s, the regulator faces a tradeoff in enforcing units of s and p only for s below \$5000. Recall that the baseline enforcement cost (in which $\theta_s = \theta_p = 0$) is \$1600. When the regulator chooses s = \$5000 and forecasts that $\theta_s = \$5000$, the regulatory cost of achieving the socially optimal expected sanction of \$2000 falls to \$1200. This obtains because the potential violator's overestimation of

either p or s does some of the regulation for the regulator—the overestimation provides free units of regulatory effort to the regulator. In the terminology of Allcott *et al.* (2019, 207-211), the potential violator's *internality* has the effect of taxing oneself, in this case for the social good.

Turning now to Case 3—our first case of compound misperception—the model illustrates, mutatis mutandis, that if *both* p and s are overestimated, the reductions to enforcement costs reinforce each other; one can show that enforcement cost falls unequivocally. Indeed, from a regulatory perspective, this Case 3 is the most advantageous set of circumstances for which society could hope. It bears repeating that this state of affairs obtains when compound misperceptions by potential violators are recognized and maintained by regulatory policy. Cases 4, 5 and 6 also yield clear results in terms of how misperception affects the regulator's enforcement cost—but in the opposite direction. If potential violators *underestimate* the probability p of apprehension, and/or if they *underestimate* the objective sanction s that they face upon apprehension, then society will have either an inefficiently high rate of violation or society will face a higher enforcement cost than if potential violators correctly perceived p and s.

Finally, Cases 7 and 8 reflect the fact that mixed results are possible such that whether enforcement cost rises, falls or remains the same depends on the relative magnitudes of the misperceptions per dimension. For instance, if the potential violator overestimates p by a large margin but underestimates s by a small margin, the net cost to enforce the socially optimal sanction could certainly be less than the enforcement cost in the baseline, no-misperception case.

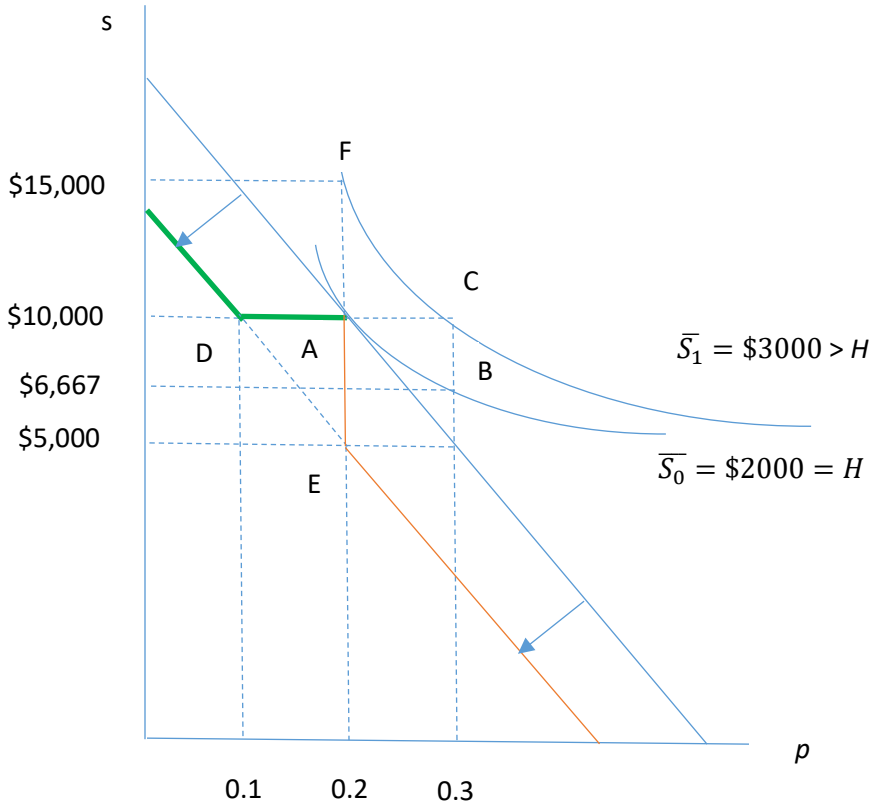

Figure 1: Enforcement cost impacts of potential violator misperceptions

3. Conclusions and Directions for Future Research

This paper began with the observation that the economics literature does not yet feature a general model that enables theoretical exploration of multidimensional misperception upon deterrence policy. At the same time, the literature contains empirical studies from a wide range of contexts, including energy, health, and intellectual property, where agent misperceptions of the market or regulatory environment occur and must be optimally managed. Thus, taking potential misperceptions into account in our theoretical modeling of agent decision-making is important if we are to have confidence that our policies have salience and work as intended. The generalized model presented herein provides a framework that combines many previous studies that investigate theoretically or empirically some elements of the enforcement challenge but not the most general set of elements. The more general model can shed light on additional opportunities for Pareto-improvements in our policy-making. In particular, the generalized model shows how some forms of misperception lead to regulatory cost savings that appear to be unrealized heretofore. The model shows that if potential violators overestimate one or both of the probability of apprehension or sanction if apprehended, the potential violator's internality enables the regulator to achieve her regulatory goal (i.e., to project the socially efficient expected sanction) at a lower regulatory cost than if potential violators do not misperceive the objective probability and/or the objective sanction. The regulator finds it to be particularly handy if potential violators overestimate both the probability and the sanction, as the social benefits from overestimation—net of regulatory costs—compound. Of course, the opposite conclusion is reached if both the objective probability and the objective sanction are *underestimated*. In that case, the model shows that if the regulator is given exogenous budget B to enforce the socially optimal expected objective sanction (ps)—socially optimal in the sense that the expected sanction equals the expected marginal public harm from the potential violator's activity—the regulator will find that budget B in the presence of agent underestimation of one or both parameters p and s will not be sufficient. With a relatively low enforcement budget, agents will commit too many violations and public harm will be greater than is socially efficient. If additional funds are allocated, the model shows the optimal direction for deploying those funds.

Another important policy implication from the generalized model is that the regulator needs to study the costs of changing the objective parameters p and s compared to the costs of correcting the agents' misperceptions θ_s and θ_p of those parameters p and s. For instance, if empirical studies in a particular context suggest that potential violators are underestimating p by 0.1 units (i.e., that $\theta_p = -0.1$), the general model explored herein reminds regulators that there are opportunities to either raise the objective level of p by 0.1 or to correct θ_p to equal zero—and the incremental costs of these corrections may not be the same. Indeed, information campaigns to correct misperceptions may have low to zero marginal costs—given that information such as presented on websites is nonrival in consumption—whereas raising objective levels of p could entail deployment of resources that are rival in consumption (i.e., an additional patrol car deployed in sector A cannot also be deployed in sector B).

As far as future directions for research, the analysis thus far assumes for simplicity that potential violators have risk-neutral preferences. Taking more general preferences into account would be insightful and valuable. Second, the theoretical framework presented herein facilitates a wide range of empirical work of use in estimating regulatory enforcement costs in the presence of both endogenous and exogenous misperceptions by potential violators.

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